Effect of Thermo-Mechanical Loading on Interphase and Particle Fractures of Titanium Oxide /AA4015 Alloy Particle-Reinforced Composites

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Abstract: *In the present work, the AA4015/* TiO_2 *metal matrix composites were manufactured at 10% and 30% volume fractions of* TiO_2. *The composites were subjected to mechanical and thermal loads. The microstructure of AA4015 alloy/* TiO_2 *reveals the fracture of interphase and also the debris of fractured interphase.*

Keywords: *AA4015, titanium oxide, spherical nanoparticle, RVE model, finite element analysis, interphase fracture.*

1. INTRODUCTION

Composite materials are known to have excellent stiffness and strength characteristics. Thermo-Mechanical loading leads to the initiation and propagation of widespread microstructural damage, often starting with interphasial failure, followed by fracture of the matrix and/or particles in the particle reinforced metal matrix composites. The problems in finding an accurate description of interphase properties are mainly due to the inhomogeneity of the material, i.e. the high stiffness ratio between particles and matrix. In characterizing interphase conditions, experiments on model composites are often accompanied by numerical analyses, qualitatively describing the results of the experiments. To describe the influence of the interphase, numerical micromechanical simulations are often used as an effective too1 [1, 2]. A lot of research was carried out to assess the interface behavior in particle reinforced metal matrix composites under tensile loading using finite element analysis approach [3-18].

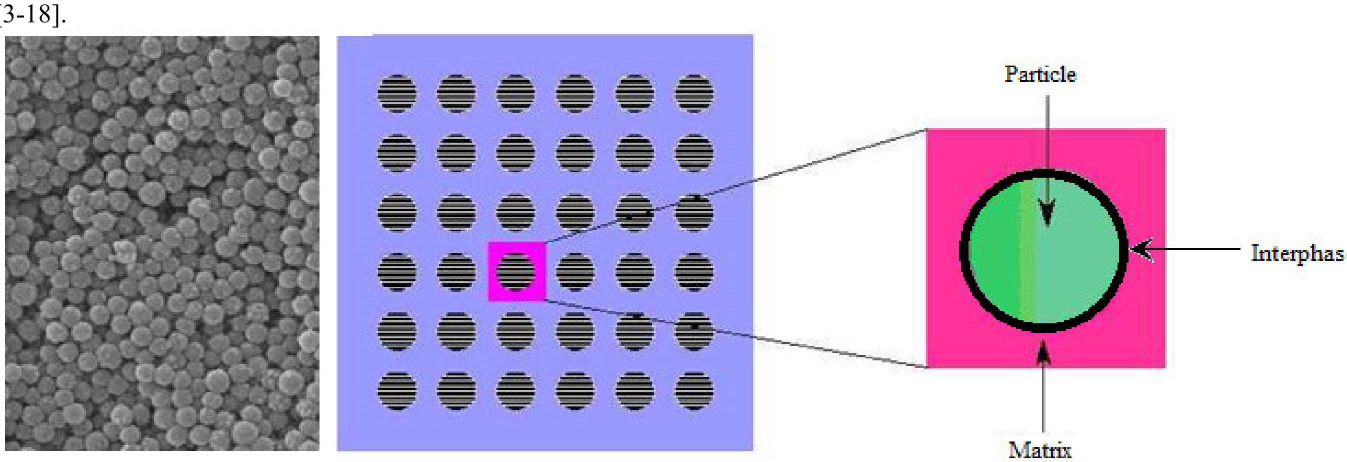

Figure 1: The interphase in a nanoparticle-reinforced composite.

The great versatility of Titanium oxide (TiO_2) is owing to its various forms and sizes. Titanium dioxides may be used in the form of microscale pigments or as nano-objects. Their crystal structures may vary: depending on the arrangement of TiO_2 atoms, one differentiates between rutile and anatase modifications. In the present work, the effect of thermo-mechanical loading on the fracture in AA4015 alloy/TiO_2 composites was examined. The shape TiO_2 nanoparticle considered in this work is spherical. The periodic particle distribution was a square array as shown in figure 1. Both microscopic and micromechanics methods were employed to assess fracture in the composites.

2. MATERIALS METHODS

The matrix material was AA4015 alloy. The reinforcement material was TiO_2 nanoparticles of average size 100nm. The mechanical properties of materials used in the present work are given in table 1.

Table 1: Mechanical properties of AA4015 matrix and TiO_2 nanoparticles

Property	AA4015	TiO_2
Density, g/cc	2.71	4.05
Elastic modulus, GPa	68.9	288.0
Coefficient of thermal expansion, 10^{-6} 1/^{o}C	18.0	11.8
Specific heat capacity, J/kg/^{o}C	850	697
Thermal conductivity, W/m/^{o}C	138	11.8
Poisson's ratio	0.34	0.29

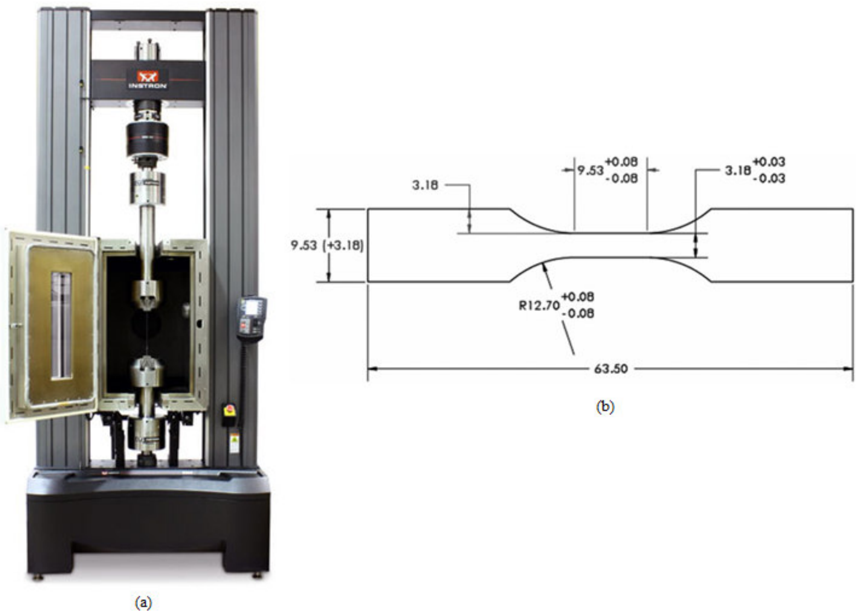

Figure 2: Tensile testing: UTM with temperature controlled chamber and (b) shape and dimensions of tensile specimen.

AA4015 alloy/TiO_2 composites were fabricated by the stir casting process and low pressure casting technique with argon gas at 3.0 bar. The composite samples were give solution treatment and cold rolled to the predefined size of tensile specimens. The heat-treated samples were machined to get flat-rectangular specimens (figure 2) for the tensile tests. The tensile specimens were placed in the grips of a Universal Test Machine (UTM) with temperature controlled chamber at a specified grip separation and pulled until failure. The test speed was 2 mm/min. A strain gauge was used to determine elongation. In the current work, a cubical representative volume element (RVE) was implemented to analyze the tensile behavior AA4015/TiO_2 nanoparticle composites at two (10% and 30%) volume fractions of TiO_2 and at different temperatures. The large strain PLANE183 element was used in the matrix in all the models. In order to model the adhesion between the matrix and the particle, a CONTACT 172 element was used.

3. RESULTS AND DISCUSSION

The optical micrograph as shown in figure 4 reveals uniform distribution of TiO_2 particles in AA4015 alloy matrix.

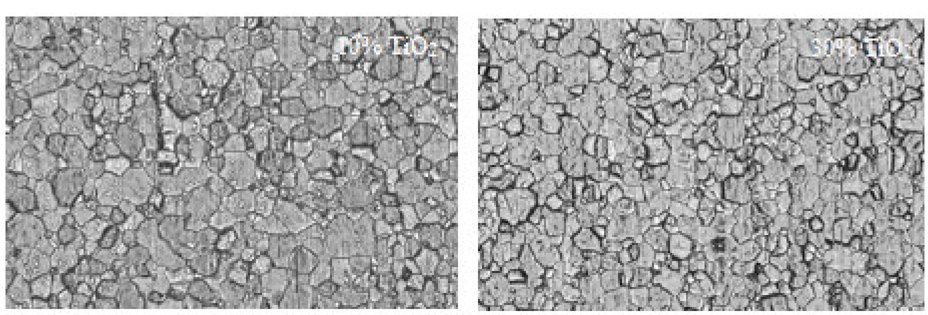

Figure 3: Microstructure showing distribution of TiO_2 nanoparticles in AA4015 alloy matrix.

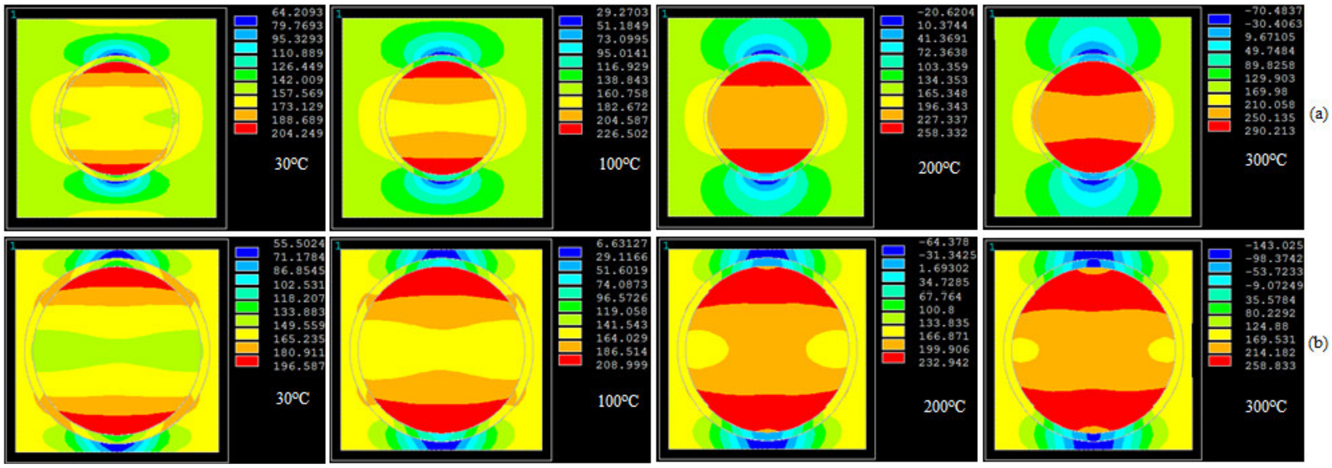

Figure 4: FEA results of tensile stress induced along load direction in the composites comprising of: (a) 10% TiO_2 and (b) 30% TiO_2.

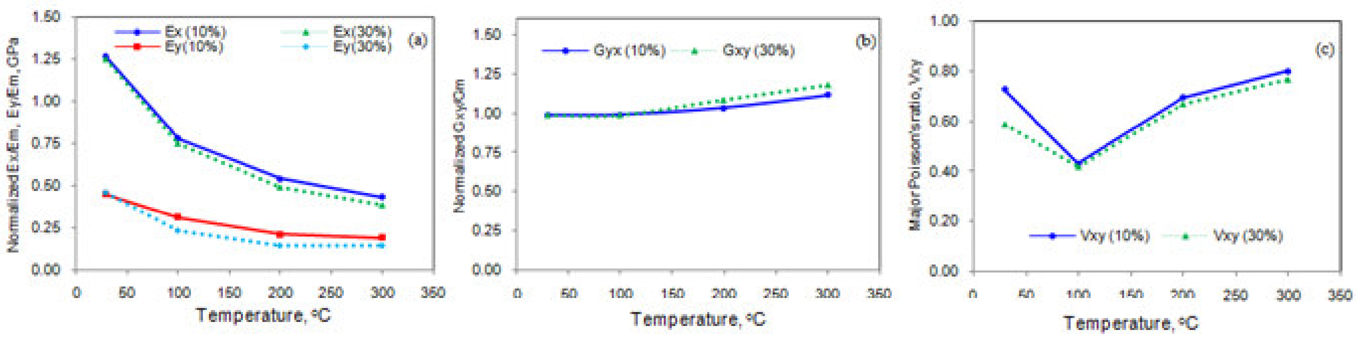

Figure 5: Effect of temperature on stiffness of AA4015/ TiO_2 composites.

3.1 Thermo-Mechanical Behavior

Figure 4 represents the tensile stresses induced in the AA4015/ TiO_2 composites along the load direction. The tensile stress increases with increase of temperature and it decreases with increase of volume fraction of AA4015/TiO_2 in AA4015 alloy matrix. The normalized elastic modulus is shown in figure 5a. The elastic modulus is normalized with the elastic modulus of AA4015 alloy. The stiffness of the composites decreases with increase of temperature. The stiffness of AA4015 alloy/10% TiO_2 composites is higher than that of AA4015 alloy/30% TiO_2 composites with regard to increase of temperature. The normalized stiffness along the normal direction is lower than that along the load direction. The normalized shear modulus increases with volume fraction of TiO_2 (figure 5b). Initially, the major Poisson's ratio decrease from 30°C to 100°C and later on it increases with temperature from 100°C to 300°C (figure 5c).

3.2 Fracture Analysis

If the particle deforms in an elastic manner (according to Hooke's law) then,

$$\tau = \frac{n}{2}\sigma_p \qquad (1)$$

where σ_p is the particle stress. If particle fracture occurs when the stress in the particle reaches its ultimate tensile strength, $\sigma_{p,uts}$, then setting the boundary condition at

$$\sigma_p = \sigma_{p,\,uts} \qquad (2)$$

The relationship between the strength of the particle and the interfacial shear stress is such that if

$$\sigma_{P,uts} < \frac{2\tau}{n} \qquad (3)$$

Then the particle will fracture. From the figure 6b, it is observed that the TiO_2 nanoparticle was not fractured as the condition in Eq. (3) is not satisfied below 300°C and at 300°C the particle fracture is initiated. This is due to CTE mismatch between TiO_2 nanoparticles and AA4015 alloy matrix. For the interfacial debonding/yielding to occur, the interfacial shear stress reaches its shear strength:

$$\tau = \tau_{max} \qquad (4)$$

For particle/matrix interfacial debonding can occur if the following condition is satisfied:

$$\tau_{max} < \frac{n\sigma_p}{2} \tag{5}$$

It is observed from figure 67a that the interphase debonding occurs between TiO_2 nanoparticle and AA4015 alloy matrix as the condition in Eq.(5) is satisfied. The debonding phenomenon is high in the composites comprising of 30% TiO_2.

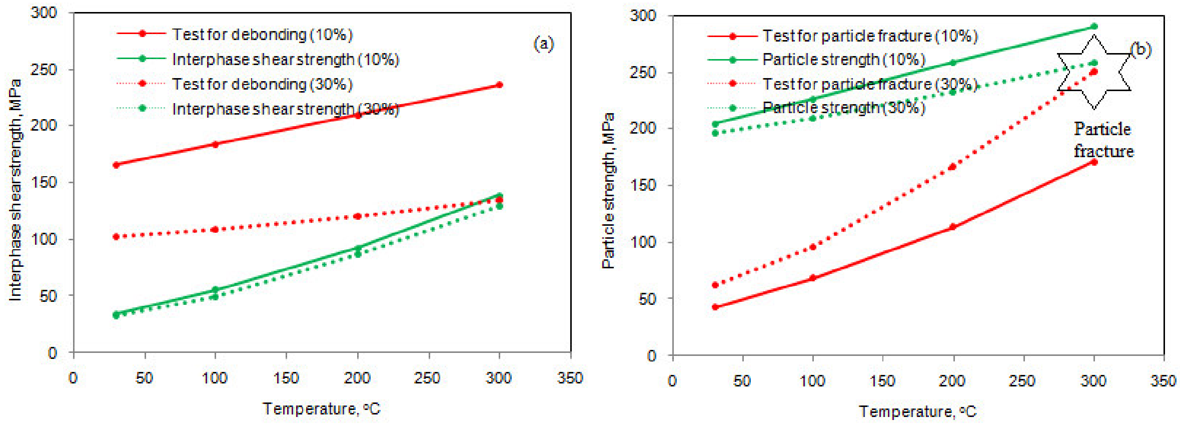

Figure 6: Criterion for interfacial debonding (a) and for particle fracture (b).

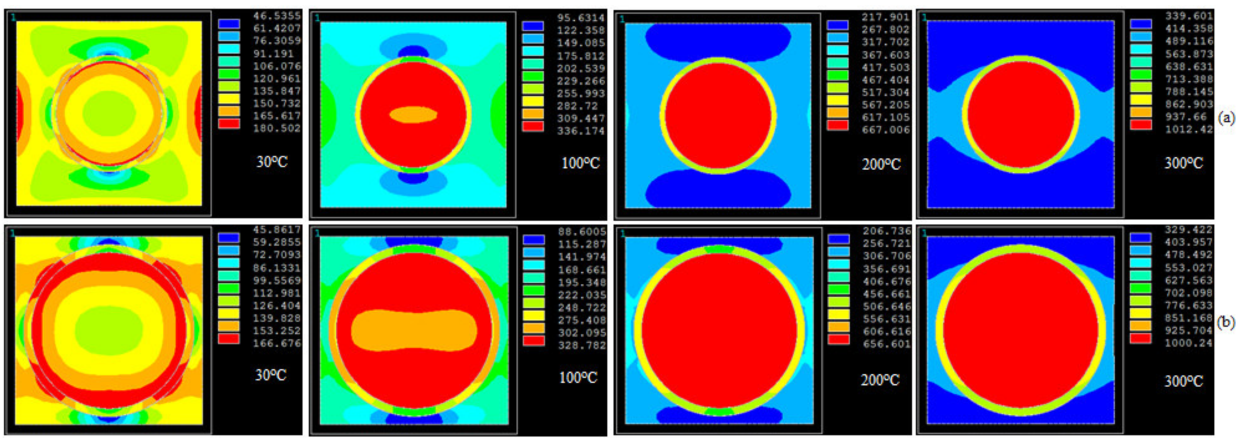

Figure 8: Images of von Mises stresses obtained from FEA: (a) AA4015/10% TiO_2 and (b) AA4015/30% TiO_2 composites.

The von Mises stress induced at the interface are higher than that induced in the nanoparticle (figure 7). Hence, the interfacial interphase fracture was occurred between the particle and the matrix. At 300°C of thermal loading, the particle fracture is initiated due to thermal shock. The microstructure shown in figure 8 confirms the occurrence of interphase and particle fractures in the composites. The interphase debonding increases with increase of temperature.

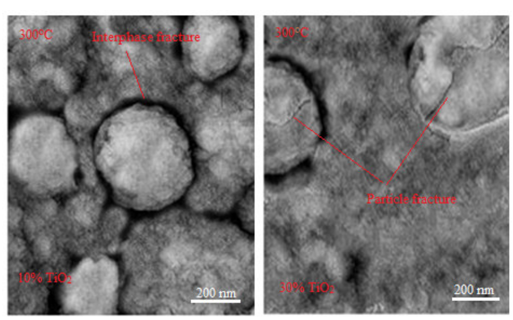

Figure 9: Microstructure showing the interphase and particle fracture in AA4015 alloy/ TiO_2 composites.

4. CONCLUSION

The microstructure of AA4015 alloy/ TiO_2 composites reveals the uniform distribution of TiO_2 nanoparticles in the matrix. The shear stress is high at the interface resulting to interphase debonding in AA4015/ TiO_2 composites. The particle fracture is also initiated at 300^oC. The microstructure obtained from the experimental samples confirms the fracture of interphase between the TiO_2 particles and AA4015 alloy matrix and particle fracture too.

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